Memorable Teaching Moments

Climate Change and Biology:
Helping students understand how global changes affect life on earth

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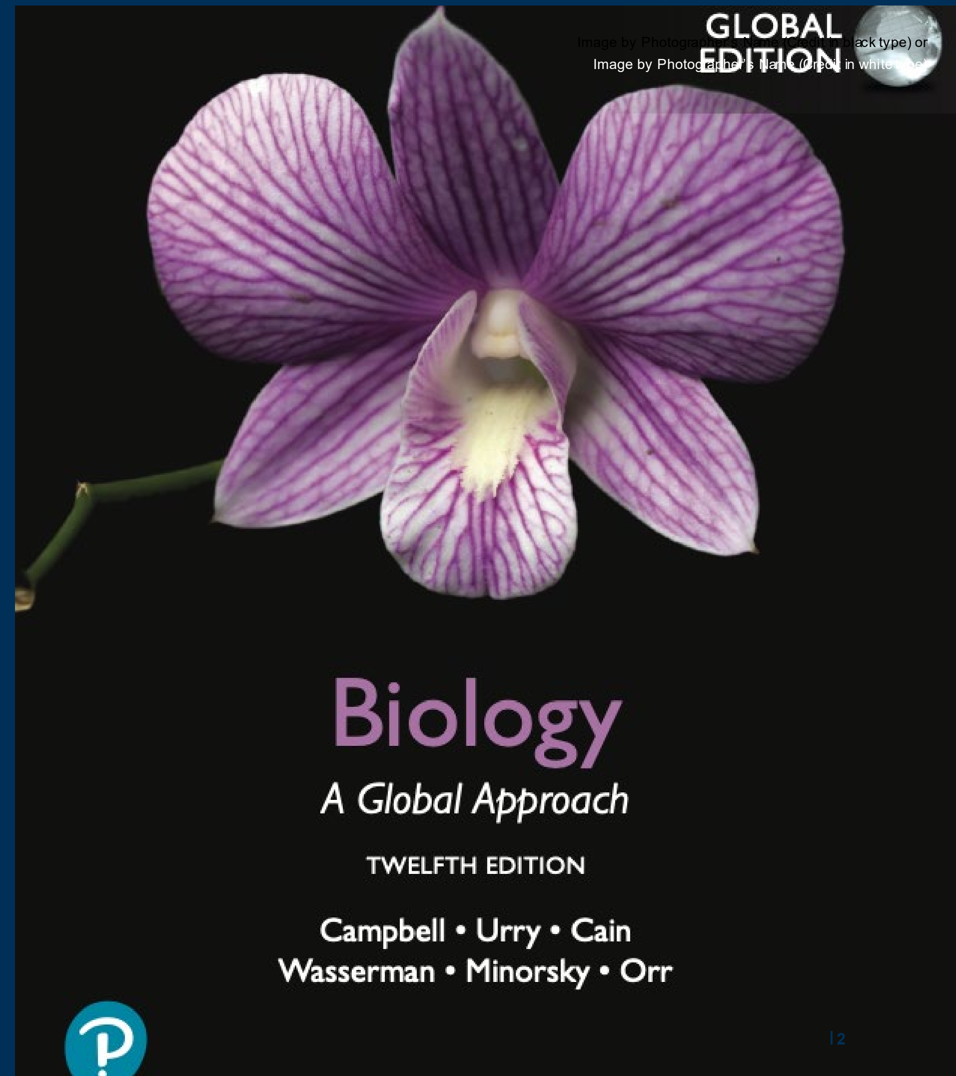
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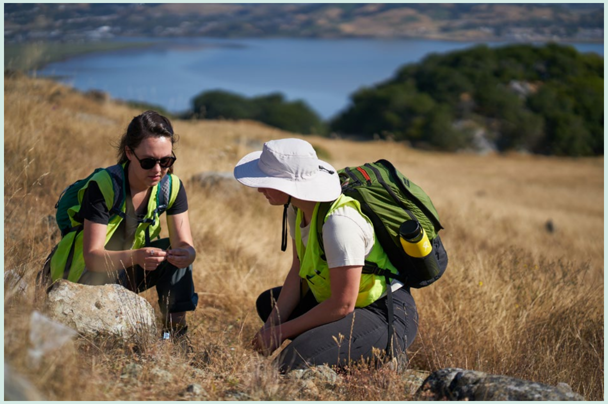


Strategies for integrating global climate change into your General Biology course

1. Start from the beginning of the course
2. Highlight CC frequently throughout the course, at different levels of biology (examples)
3. Have students work with data so they can draw their own conclusions, and see how models are built
4. Emphasize importance of students' role in continuing the public conversation about possible solutions

1. Introduce climate change content from the beginning of the course

and release oxygen to the air (see Figure 1.11). The environment is also affected by organisms. For instance, in addition to taking up water and minerals from the soil, the roots of a plant break up rocks as they grow, contributing to the formation of soil. On a global scale, plants and other photosynthetic organisms have generated all the oxygen in the atmosphere.

Like other organisms, we humans interact with our environment. Our interactions sometimes have dire consequences: For example, over the past 150 years, humans have greatly increased the burning of fossil fuels (coal, oil, and gas). This practice releases large amounts of carbon dioxide (CO_2) and other gases into the atmosphere, causing heat to be trapped close to Earth's surface (see Figure 56.29). Scientists calculate that the CO_2 added to the atmosphere by human activities has increased the average temperature of the planet by about 1°C since 1900. At the current rates that CO_2 and other gases are being added to the atmosphere, global models predict an additional rise of at least 3°C before the end of this century.

This ongoing global warming is a major aspect of **climate change**, a directional change to the global climate that lasts for three decades or more (as opposed to short-term changes in the weather). But global warming is not the only way the climate is changing: Wind and precipitation patterns are also shifting, and extreme weather events such as storms and droughts are occurring more often. Climate change has already affected organisms and their habitats all over the planet. For example, polar bears have lost much of the ice platform from which they hunt, leading to food shortages and increased mortality rates. As habitats deteriorate, hundreds of plant and animal species are shifting their ranges to more suitable locations—but for some, there is insufficient suitable habitat, or they may not be able to migrate quickly enough. As a result, the populations of many species are shrinking in size or even disappearing **(Figure 1.12)**. (For more examples of how climate change is affecting life on Earth, see Make Connections Figure 56.30.)

The loss of populations due to climate change can ultimately result in extinction, the permanent loss of a species.

▶ Figure 1.12 Threatened by global warming. A warmer environment causes lizards in the genus *Sceloporus* to spend more time in refuges from the heat, reducing time for foraging. Their food intake drops, decreasing reproductive success. Surveys of 200 *Sceloporus* populations in Mexico show that 12% of these populations have disappeared since 1975.

As we'll explore in greater detail in Concept 56.4, the consequences of these changes for humans and other organisms may be profound.

Having considered four of the unifying themes (organization, information, energy and matter, and interactions), let's now turn to evolution. There is consensus among biologists that evolution is the core theme of biology, and it is discussed in detail in the next section.

CONCEPT CHECK 1.1

1. Starting with the molecular level in Figure 1.3, write a sentence that includes components from the previous (lower) level of biological organization, for example: "A molecule consists of *atoms* bonded together." Continue with organelles, moving up the biological hierarchy.
2. Identify the theme or themes exemplified by (a) the sharp quills of a porcupine, (b) the development of a multicellular organism from a single fertilized egg, and (c) a hummingbird using sugar to power its flight.
3. **WHAT IF?** For each theme discussed in this section, give an example not mentioned in the text.

For suggested answers, see Appendix A.

CONCEPT 1.2

The Core Theme: Evolution accounts for the unity and diversity of life

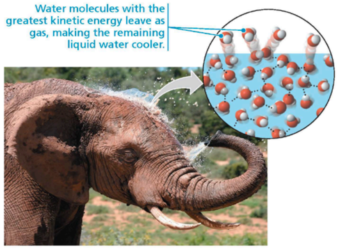
EVOLUTION An understanding of evolution helps us to make sense of everything we know about life on Earth. As the fossil record clearly shows, life has been evolving for billions of years, resulting in a vast diversity of past and present organisms. But along with the diversity there is also unity, in the form of shared features. For example, while sea horses, jackrabbits, hummingbirds, and giraffes all look very different, their skeletons are organized in the same basic way.

The scientific explanation for the unity and diversity of organisms is **evolution**: a process of biological change in which species accumulate differences from their ancestors as they adapt to different environments over time. Thus, we can account for differences between two species (diversity) with the idea that certain heritable changes occurred after the two species diverged from their common ancestor. However, they also share certain traits (unity) simply because they have descended from a common ancestor. An abundance of evidence of different types supports the occurrence of evolution and the mechanisms that describe how it takes place, which we'll explore in detail in Chapters 21–25. To quote one of the founders of modern evolutionary theory, Theodosius Dobzhansky, "Nothing in biology makes sense except in the light of evolution." To understand this statement, we need to examine how biologists think about the vast diversity of life on the planet.

2. Highlight climate change throughout the course

- Properties of water: Polar ice melting

▼ Figure 3.6 Evaporative cooling. In hot weather, an elephant sprays water from its trunk onto its head. Evaporation of this water cools the elephant down.



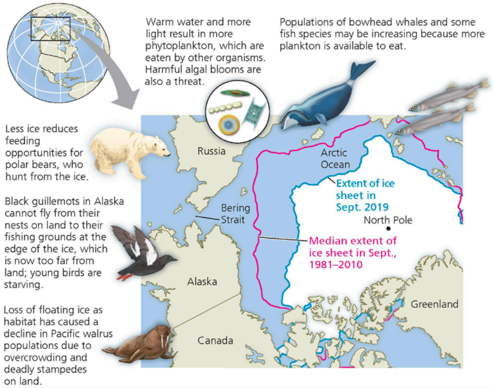
Floating of Ice on Liquid Water

Water is one of the few substances that are less dense as a solid than as a liquid. As a result, ice floats on liquid water. While other materials contract and become denser when they solidify, water expands. The cause of this exotic behavior is, once again, hydrogen bonding. At temperatures above 4°C, water behaves like other liquids, expanding as it warms and contracting as it cools. As the temperature falls from 4°C to 0°C, water begins to freeze because more and more of its molecules are moving too slowly to break hydrogen bonds. At 0°C, the molecules become locked into a crystalline lattice, each water molecule hydrogen-bonded to four partners (see Figure 3.1). The hydrogen bonds keep the molecules at "arm's length," far enough apart to make ice about 10% less dense (10% fewer molecules in the same volume) than liquid water at 4°C. When ice absorbs enough heat for its temperature to rise above 0°C, hydrogen bonds between molecules are disrupted. As the crystal collapses, the ice melts and molecules have fewer hydrogen bonds, allowing them to slip closer together. Water reaches its greatest density at 4°C and then begins to expand as the molecules move faster. Even in liquid water, many of the molecules are connected by hydrogen bonds, though only transiently: The hydrogen bonds are constantly breaking and re-forming.

The ability of ice to float due to its lower density is an important factor in the suitability of the environment for life. If ice sank, then eventually ponds, lakes, and even oceans could freeze solid, making life as we know it impossible on Earth. During summer, only the upper few inches of the ocean would thaw. Instead, when a deep body of water cools, the ice floats, insulating the liquid water below. This prevents it from freezing and allows life to exist under the frozen surface, as shown in Figure 3.1. Besides insulating the water below, ice also provides a solid habitat for some animals, such as polar bears and seals.

Many scientists are worried that these bodies of ice are at risk of disappearing. Global warming, which is caused by carbon dioxide and other "greenhouse" gases in the atmosphere (see Figure 56.30), is having a profound effect on icy environments around the globe. In the Arctic, the average air temperature has risen 2.2°C just since 1961. This temperature increase has affected the seasonal balance between Arctic sea ice and liquid water, causing ice to form later in the year, to melt earlier, and to cover a smaller area. The rate at which glaciers and Arctic sea ice are disappearing is posing an extreme challenge to animals that depend on ice for their survival (**Figure 3.7**).

▼ Figure 3.7 Effects of climate change on the Arctic. Warmer temperatures in the Arctic cause more sea ice to melt in the summer. The loss of ice disrupts the ecosystem, affecting many species. (Map data is from the National Snow and Ice Data Center.)



2. Highlight climate change throughout the course

- Properties of water: Polar ice melting
- Photosynthesis: C3 vs C4 vs CAM

Scientific Skills Exercise

Making Scatter Plots with Regression Lines

Does Atmospheric CO_2 Concentration Affect the Productivity of Agricultural Crops? The atmospheric concentration of CO_2 has been rising globally, and scientists wondered whether this would affect C_3 and C_4 plants differently. In this exercise, you will make a scatter plot to examine the relationship between CO_2 concentration and growth of both corn (maize), a C_4 crop plant, and velvetleaf, a C_3 weed found in cornfields.

How the Experiment Was Done For 45 days, researchers grew corn and velvetleaf plants under controlled conditions, where all plants received the same amounts of water and light. The plants were divided into three groups, and each was exposed to a different concentration of CO_2 in the air: 350, 600, or 1,000 ppm (parts per million).

Data from the Experiment The table shows the dry mass (in grams) of corn and velvetleaf plants grown at the three concentrations of CO_2. The dry mass values are averages calculated from the leaves, stems, and roots of eight plants.

	350 ppm CO_2	600 ppm CO_2	1,000 ppm CO_2
Average dry mass of one corn plant (g)	91	89	80
Average dry mass of one velvetleaf plant (g)	35	48	54

Data from D. T. Patterson and E. P. Flint, Potential effects of global atmospheric CO_2 enrichment on the growth and competitiveness of C_3 and C_4 weed and crop plants, *Weed Science* 28(1):71–75 (1980).

▶ Corn plant surrounded by invasive velvetleaf plants.

INTERPRET THE DATA

1. To explore the relationship between the two variables, it is useful to graph the data in a scatter plot, and then draw a regression line. **(a)** First, place labels for the dependent and independent variables on the appropriate axes. Explain your choices. **(b)** Plot the data points for corn and velvetleaf using different symbols for each set of data, and add a key for the two symbols. (For additional information about graphs, see the Scientific Skills Review in Appendix D.)
2. Draw a "best-fit" line for each set of points. A best-fit line does not necessarily pass through all or even most points. Instead, it is a straight line that passes as close as possible to all data points from that set. Draw a best-fit line for each set of data. Because placement of the line is a matter of judgment, two individuals may draw two slightly different lines for a given set of points. The line that actually fits best, a regression line, can be identified by squaring the distances of all points to any candidate line, then selecting the line that minimizes the sum of the squares. (See the graph in the Scientific Skills Exercise in Chapter 3 for an example of a linear regression line.) Excel or other software programs, including those on a graphing calculator, can plot a regression line once data points are entered. Using either Excel or a graphing calculator, enter the data points for each data set and have the program draw the two regression lines. Compare them to the lines you drew.
3. Describe the trends shown by the regression lines in your scatter plot. **(a)** Compare the relationship between increasing concentration of CO_2 and the dry mass of corn to that for velvetleaf. **(b)** Considering that velvetleaf is a weed invasive to cornfields, predict how increased CO_2 concentration may affect interactions between the two species.
4. Based on the data in the scatter plot, estimate the percentage change in dry mass of corn and velvetleaf plants if atmospheric CO_2 concentration increased from 390 ppm (current levels) to 800 ppm. **(a)** What is the estimated dry mass of corn and velvetleaf plants at 390 ppm? 800 ppm? **(b)** To calculate the percentage change in mass for each plant, subtract the mass at 390 ppm from the mass at 800 ppm (change in mass), divide by the mass at 390 ppm (initial mass), and multiply by 100. What is the estimated percentage change in dry mass for corn? For velvetleaf? **(c)** Do these results support the conclusion from other experiments that C_3 plants grow better than C_4 plants under increased CO_2 concentration? Why or why not?

➔ **Instructors:** A version of this Scientific Skills Exercise can be assigned in **Mastering Biology.**

C_4 photosynthesis is considered more efficient than C_3 photosynthesis because it uses less water and resources. On our planet today, the world population and demand for food are rapidly increasing. At the same time, the amount of land suitable for growing crops is decreasing due to the effects of global climate change, which include an increase in sea level as well as a hotter, drier climate in many regions. To address issues of food supply, scientists in the Philippines have been working on genetically modifying rice—an important food staple that is a C_3 crop—so that it can instead carry out C_4 photosynthesis. Results so far seem promising, and these researchers estimate that the yield of C_4 rice might be 30–50% higher than C_3 rice with the same input of water and resources.

CAM Plants

A second photosynthetic adaptation to arid conditions has evolved in pineapples, many cacti, and other succulent (water-storing) plants, such as aloe and jade plants. These plants open their stomata at night and close them during the day, just the reverse of how other plants behave. Closing stomata during the day helps desert plants conserve water, but it

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2. Highlight climate change throughout the course

- Properties of water: Polar ice melting
- Photosynthesis: C3 vs C4 vs CAM
- Viruses: Emerging diseases

of seasonal flu viruses have been circulating among humans for long enough that most components are recognized by the immune system. However, these viruses still undergo mutation and reassortment of genome segments, and variations of the HA protein are used each year to generate vaccines against the strains predicted most likely to occur the following year.

As we have seen, emerging viruses are usually existing viruses that mutate, spread more widely in the current host species, or spread to new host species. Changes in host behavior or environmental changes can increase the viral traffic responsible for emerging diseases. For instance, new roads built through remote areas can allow viruses to spread between previously isolated human populations. Also, the destruction of forests to expand cropland can bring humans into contact with animals that host infectious viruses. Finally, genetic mutations and changes in host ranges can allow viruses to jump between species. Many viruses are transmitted by mosquitoes. A dramatic expansion of the disease caused by the chikungunya virus occurred in the mid-2000s when a mutation allowed it to infect not only the mosquito species *Aedes aegypti* but also the related *Aedes albopictus*. Insecticides and mosquito netting over beds are crucial tools in public health attempts to prevent diseases carried by mosquitoes **(Figure 26.11)**.

▼ Figure 26.11 Netting as protection against virus-carrying mosquitoes.

Recently, scientists have become concerned about the possible effects of climate change on worldwide viral transmission. Dengue fever, also mosquito-borne, has appeared in Florida and Portugal, regions where it had not been seen before. The possibility that global climate change has allowed mosquito species carrying these viruses to expand their ranges and interact more is troubling because of the increased chance of a mutation allowing a virus to jump to a new host. This is an area of active research by scientists applying climate change models to what is known about the habitat requirements of mosquito species.

Viral Diseases in Plants

More than 2,000 types of viral diseases of plants are known, accounting for an annual loss of over $30 billion worldwide due to destruction of crops. Common signs of viral infection include bleached or brown spots on leaves and fruits **(Figure 26.12)**, stunted growth, and damaged flowers or roots, all of which can diminish the yield and quality of crops.

► Figure 26.12 Immature tomato infected by a virus.

Plant viruses have the same basic structure and mode of replication as animal viruses. Most known plant viruses, including tobacco mosaic virus (TMV), have an RNA genome. Many have a helical capsid, like TMV, while others have an icosahedral capsid (see Figure 26.3b).

Viral diseases of plants spread by two major routes. In the first route, *horizontal transmission*, an external source infects the plant. Because the invading virus must get past the plant's outer protective layer of cells (the epidermis), a plant becomes more susceptible to viral infections if it has been damaged by wind, injury, or herbivores. Herbivores, especially insects, pose a double threat because they can also carry viruses, transmitting disease from plant to plant. Moreover, gardeners may transmit plant viruses inadvertently on pruning shears and other tools. The other route of viral infection is *vertical transmission*, in which a plant inherits a viral infection from a parent. Vertical transmission can occur in asexual propagation (for example, through cuttings) or in sexual reproduction via infected seeds.

Once a virus enters a plant cell and begins replicating, viral genomes and associated proteins can spread throughout the plant through plasmodesmata, the cytoplasmic connections that penetrate the walls between adjacent plant cells (see Figure 36.19). The passage of viral macromolecules from cell to cell is facilitated by virally encoded proteins that cause enlargement of plasmodesmata. Scientists have not yet devised cures for most viral plant diseases, so research efforts are focused largely on reducing disease transmission and on breeding resistant varieties of crop plants.

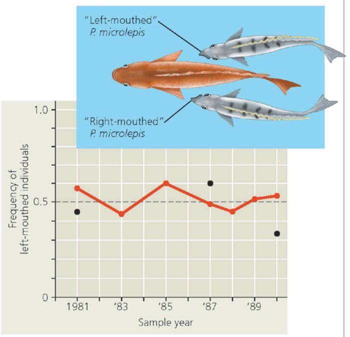
Prions: Proteins as Infectious Agents

The viruses discussed in this chapter are infectious agents that spread diseases, and their genetic material is composed of nucleic acids, whose ability to be replicated is well known. Surprisingly, there are also *proteins* that are infectious. Proteins called **prions** appear to cause degenerative brain diseases in various animal species. These diseases include scrapie in sheep; mad cow disease, which plagued the European beef industry about 20 years ago; and Creutzfeldt-Jakob disease in humans, which has caused the death of some 175 people in the United Kingdom since 1996. Prions can be transmitted in food, as may occur when people eat beef from cattle with mad cow disease. Kuru, another human disease caused by prions, was identified in the early 1900s among the South Fore indigenous people of New Guinea. When a kuru epidemic peaked there in the 1960s, scientists at first thought the disease had a genetic basis because family members also often contracted the disease. Eventually, however, investigations revealed a

2. Highlight climate change throughout the course

- Properties of water: Polar ice melting
- Photosynthesis: C3 vs C4 vs CAM
- Viruses: Emerging diseases
- Evolution: Limits of natural selection

▼ **Figure 23.17 Frequency-dependent selection.** In a population of the scale-eating fish *Perissodus microlepis*, the frequency of left-mouthed individuals (red data points) rises and falls in a regular manner. The black data points indicate the frequency of left-mouthed individuals among adults that reproduced in three sample years.



INTERPRET THE DATA *For 1981, 1987, and 1990, compare the frequency of left-mouthed individuals among breeding adults to the frequency of left-mouthed individuals in the entire population. What do the data indicate about when natural selection favors left-mouthed individuals over right-mouthed individuals (or vice versa)? Explain.*

heterozygotes, not enough become sickled to cause sickle-cell disease.

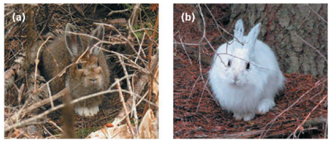
As described in **Figure 23.18**, heterozygotes for the sickle-cell allele are protected against the most severe effects of malaria, a disease caused by a parasite that infects red blood cells. One reason for this partial protection is that the body destroys sickled red blood cells rapidly, killing the parasites they harbor. Malaria is a major killer in some tropical regions. In such regions, selection favors heterozygotes over homozygous dominant individuals, who are more vulnerable to the effects of malaria, and also over homozygous recessive individuals, who develop sickle-cell disease. These selective pressures have caused the frequency of the sickle-cell allele to reach relatively high levels in areas where the malaria parasite, which is carried by mosquitoes, is common.

Why Natural Selection Cannot Fashion Perfect Organisms

Though natural selection leads to adaptation, nature abounds with examples of organisms that are less than ideally suited for their lifestyles. There are several reasons why.

1. **Selection can act only on existing variations.** Natural selection favors only the fittest phenotypes among those currently in the population, which may not be the ideal traits. New advantageous alleles do not arise on demand. For example, historically, snowshoe hares (*Lepus americanus*) have molted, changing their coats from brown to white, at a time of year that matched the onset of snowfall, providing camouflage all winter. But due to climate change, the first snowfall now occurs later in the year. In some populations, the date at which the hares change their coat color has remained the same, causing the hares to be poorly camouflaged early in winter and thus easier for predators to spot and kill (**Figure 23.19**). Because their gene pools lack alleles that could delay when molting occurs, these populations have been unable to adapt to changing conditions.
2. **Evolution is limited by historical constraints.** Each species has a legacy of descent with modification from ancestral forms. Evolution does not scrap the ancestral anatomy and build each new complex structure from scratch; rather, evolution co-opts existing structures and adapts them to new situations. We could imagine that if a terrestrial animal were to adapt to an environment in which flight would be advantageous, it might be best just to grow an extra pair of limbs that would serve as wings. However, evolution does not work this way; instead, it operates on the traits an organism already has. Thus, in birds and bats, an existing pair of limbs took on new functions for flight as these organisms evolved from nonflying ancestors.
3. **Adaptations are often compromises.** Each organism must do many different things. A seal spends part of its time on rocks; it could probably walk better if it had legs instead of flippers, but then it would not swim nearly as well. We humans owe much of our versatility and athleticism to our prehensile hands and flexible limbs, but these also make us prone to sprains, torn ligaments, and dislocations: Structural reinforcement has been compromised for agility. Organisms face many such *trade-offs* in which the ability to perform one function may reduce the ability to perform another—and as with seals and humans, those trade-offs can restrict adaptive evolution.

▼ **Figure 23.19 Lack of variation in a population can limit adaptation.** For the snowshoe hare, changing its coat color from brown **(a)** to white **(b)** too early is disadvantageous, but the population lacks alleles that would encode a delay in molting.



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2. Highlight climate change throughout the course

- Properties of water: Polar ice melting
- Photosynthesis: C3 vs C4 vs CAM
- Viruses: Emerging diseases
- Evolution: Limits of natural selection
- Evolution: Hybrid zone effects

Hybrid Zones and Environmental Change

A change in environmental conditions can alter where the habitats of interbreeding species meet. When this happens, an existing hybrid zone can move to a new location, or a novel hybrid zone may form.

For example, black-capped chickadees (*Poecile atricapillus*) and Carolina chickadees (*P. carolinensis*) interbreed in a narrow hybrid zone that runs from New Jersey to Kansas. Recent studies have shown that the location of this hybrid zone has shifted northward as the climate has warmed (**Figure 24.14**). In another example, a series of warm winters prior to 2003 enabled the southern flying squirrel (*Glaucomys volans*) to expand northward into the range of the northern flying squirrel, *G. sabrinus*. Previously, the ranges of these two species had not overlapped. Genetic analyses showed that these flying squirrels began to hybridize where their ranges came into contact, thereby forming a novel hybrid zone induced by climate change.

Finally, note that a hybrid zone can be a source of novel genetic variation that improves the ability of one or both parent species to cope with changing environmental conditions. This can occur when an allele found only in one parent species is transferred first to hybrid individuals and then to the other parent species when hybrids breed with the second parent species. Recent genetic analyses have shown that hybridization has been a source for such novel genetic variation in some insect, mammal, bird, and plant species. In the **Problem-Solving Exercise**, you can examine one such example: a case in which hybridization may have led to the transfer of insecticide-resistance alleles between species of mosquitoes that transmit malaria.

▼ **Figure 24.14 A shift in a hybrid zone resulting from climate change.** Black-capped **(a)** and Carolina chickadees **(b)** interbreed in a hybrid zone that runs from Kansas to New Jersey. In Pennsylvania, the center of this hybrid zone moved 12 km to the north from 2002 to 2012. This shift is consistent with predictions based on the warmer winter temperatures that have resulted from climate change.

(a) Black-capped chickadee (*Poecile atricapillus*)

(b) Carolina chickadee (*Poecile carolinensis*)

PROBLEM-SOLVING EXERCISE

Is hybridization promoting insecticide resistance in mosquitoes that transmit malaria?

Malaria is a leading cause of human illness and mortality worldwide, with 200 million people infected and 600,000 deaths each year. In the 1960s, the incidence of malaria was reduced, owing to the use of insecticides that killed mosquitoes in the genus *Anopheles*, which transmit the disease from person to person. But today, mosquitoes are becoming resistant to insecticides—causing a resurgence in malaria.

Insecticide-treated bed nets have helped reduce cases of malaria in many countries, but resistance to insecticides is rising in mosquito populations.

Instructors: A version of this Problem-Solving Exercise can be assigned in **Mastering Biology**.

In this exercise, you will investigate whether alleles encoding resistance to insecticides have been transferred between closely related species of *Anopheles*.

Your Approach The principle guiding your investigation is that DNA analyses can detect the transfer of resistance alleles between closely related mosquito species. To find out whether such transfers have occurred, you will analyze DNA results from two species of mosquitoes that transmit malaria (*Anopheles gambiae* and *A. coluzzii*) and from *A. gambiae* × *A. coluzzii* hybrids.

Your Data Resistance to DDT and other insecticides in *Anopheles* is affected by a sodium channel gene, *kdr*. The *r* allele of this gene confers resistance, while the wild-type (+/+) genotype is not resistant. Researchers sequenced the *kdr* gene from mosquitoes collected in Mali during three time periods: pre-2006 (2002 and 2004), 2006, and post-2006 (2009–2012). *A. gambiae* and *A. coluzzii* were collected during all three time periods, but their hybrids only occurred in 2006, the first year that insecticide-treated bed nets were used to reduce the spread of malaria. A likely explanation is that the introduction of the treated bed nets may have briefly favored hybrid individuals, which are usually at a selective disadvantage.

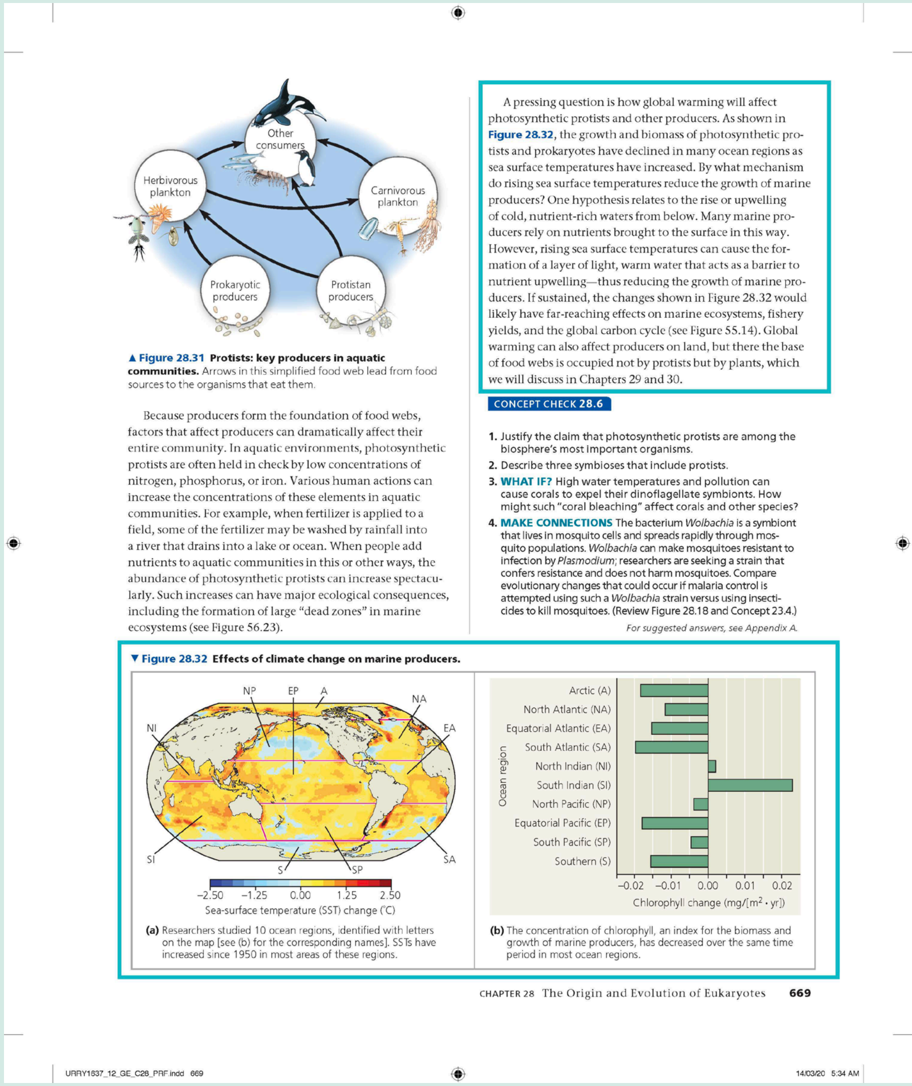
Observed numbers of mosquitoes by *kdr* genotype			
	+/+	+/*r*	*r*/*r*
A. gambiae:			
Pre-2006	3	5	2
2006	8	8	7
Post-2006	3	3	57
Hybrids: 2006	10	7	0
A. coluzzii:			
Pre-2006	226	0	0
2006	70	7	0
Post-2006	79	127	94

Your Analysis

1. **(a)** Calculate the *kdr* genotype frequencies in *A. gambiae* for each time period. To do this, divide the number of individuals that have a given genotype by the total number of individuals observed for that time period. **(b)** How did the *kdr* genotype frequencies change over time? Describe a hypothesis that accounts for these observations.
2. How did the frequencies of *kdr* genotypes change over time in *A. coluzzii*? Describe a hypothesis that accounts for these observations.
3. Do these results indicate that hybridization can lead to the transfer of adaptive alleles? Explain.
4. Predict how the transfer of the *r* allele to *A. coluzzii* populations could affect the number of malaria cases in the years immediately following the transfer.

2. Highlight climate change throughout the course

- Properties of water: Polar ice melting
- Photosynthesis: C3 vs C4 vs CAM
- Viruses: Emerging diseases
- Evolution: Limits of natural selection
- Evolution: Hybrid zone effects
- Diversity: Effects on phytoplankton



▲ **Figure 28.31 Protists: key producers in aquatic communities.** Arrows in this simplified food web lead from food sources to the organisms that eat them.

Because producers form the foundation of food webs, factors that affect producers can dramatically affect their entire community. In aquatic environments, photosynthetic protists are often held in check by low concentrations of nitrogen, phosphorus, or iron. Various human actions can increase the concentrations of these elements in aquatic communities. For example, when fertilizer is applied to a field, some of the fertilizer may be washed by rainfall into a river that drains into a lake or ocean. When people add nutrients to aquatic communities in this or other ways, the abundance of photosynthetic protists can increase spectacularly. Such increases can have major ecological consequences, including the formation of large "dead zones" in marine ecosystems (see Figure 56.23).

A pressing question is how global warming will affect photosynthetic protists and other producers. As shown in **Figure 28.32**, the growth and biomass of photosynthetic protists and prokaryotes have declined in many ocean regions as sea surface temperatures have increased. By what mechanism do rising sea surface temperatures reduce the growth of marine producers? One hypothesis relates to the rise or upwelling of cold, nutrient-rich waters from below. Many marine producers rely on nutrients brought to the surface in this way. However, rising sea surface temperatures can cause the formation of a layer of light, warm water that acts as a barrier to nutrient upwelling—thus reducing the growth of marine producers. If sustained, the changes shown in Figure 28.32 would likely have far-reaching effects on marine ecosystems, fishery yields, and the global carbon cycle (see Figure 55.14). Global warming can also affect producers on land, but there the base of food webs is occupied not by protists but by plants, which we will discuss in Chapters 29 and 30.

CONCEPT CHECK 28.6

1. Justify the claim that photosynthetic protists are among the biosphere's most important organisms.
2. Describe three symbioses that include protists.
3. **WHAT IF?** High water temperatures and pollution can cause corals to expel their dinoflagellate symbionts. How might such "coral bleaching" affect corals and other species?
4. **MAKE CONNECTIONS** The bacterium *Wolbachia* is a symbiont that lives in mosquito cells and spreads rapidly through mosquito populations. *Wolbachia* can make mosquitoes resistant to infection by *Plasmodium*; researchers are seeking a strain that confers resistance and does not harm mosquitoes. Compare evolutionary changes that could occur if malaria control is attempted using such a *Wolbachia* strain versus using insecticides to kill mosquitoes. (Review Figure 28.18 and Concept 23.4.)

For suggested answers, see Appendix A.

▼ **Figure 28.32 Effects of climate change on marine producers.**

(a) Researchers studied 10 ocean regions, identified with letters on the map [see (b) for the corresponding names]. SSTs have increased since 1950 in most areas of these regions.

(b) The concentration of chlorophyll, an index for the biomass and growth of marine producers, has decreased over the same time period in most ocean regions.

CHAPTER 28 The Origin and Evolution of Eukaryotes 669

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2. Highlight climate change throughout the course

- Properties of water: Polar ice melting
- Photosynthesis: C3 vs C4 vs CAM
- Viruses: Emerging diseases
- Evolution: Limits of natural selection
- Evolution: Hybrid zone effects
- Diversity: Effects on phytoplankton
- Plants: Food quality vs quantity

In the **Scientific Skills Exercise**, you can diagnose a mineral deficiency in leaves of an orange tree. Micronutrient shortages are less common than macronutrient shortages and tend to occur in certain geographic regions because of differences in soil composition. One way to confirm a diagnosis is to analyze the mineral content of the plant or soil. The amount of a micronutrient needed to correct a deficiency is usually small. For example, a zinc deficiency in fruit trees can usually be cured by hammering a few zinc nails into each tree trunk. Moderation is important because overdoses of a micronutrient or macronutrient can be detrimental or toxic. Too much nitrogen, for example, can lead to excessive vine growth in tomato plants at the expense of good fruit production.

Scientific Skills Exercise

Making Observations

What Mineral Deficiency Is This Plant Exhibiting? Plant growers often diagnose deficiencies in their crops by examining changes to the foliage, such as chlorosis (yellowing), death of some leaves, discoloring, mottling, scorching, or changes in size or texture. In this exercise, you will diagnose a mineral deficiency by observing a plant's leaves and applying what you have learned about symptoms from the text and Table 37.1.

Data The data for this exercise come from the photograph below of leaves on an orange tree exhibiting a mineral deficiency.

INTERPRET THE DATA

1. How do the young leaves differ in appearance from the older leaves?
2. What change do you observe in the leaves, and where in the leaves does it appear? List the three nutrients whose deficiencies give rise to this symptom. Based on the symptom's location, which one of these three nutrients can be ruled out, and why? What does the location suggest about the other two nutrients?
3. How would your hypothesis about the cause of this deficiency be influenced if tests showed that the soil was low in humus?

Instructors: A version of this Scientific Skills Exercise can be assigned in **Mastering Biology**.

Global Climate Change and Food Quality

Since plant growth is generally enhanced by increases in atmospheric CO_2 and by warming temperatures, global food production, as measured by plant biomass, is expected to increase in response to global climate change in certain parts of the world. But food production must also be judged by its quality. Unfortunately, there are indications that plants today, compared with plants in preindustrial times, are not taking up nutrients sufficiently to keep pace with their increased fixation of CO_2 into carbohydrates. For example, a study of 43 crops found significant declines in protein, Ca, P, Fe, riboflavin, and ascorbic acid from 1950 to 1999. Although this decline in food quality might be caused by a shift toward higher-yielding crops, studies of wild plants suggest that global climate change is the culprit. For example, a study revealed that the protein content of goldenrod (*Solidago canadensis*) pollen has declined by one third since the Industrial Revolution, and the change closely correlates with the rise in CO_2 that has occurred. Declines in the qualities of pollen as a food source might play a role in the widespread decline of honeybees, important pollinators whose decreasing population threatens crop production.

CONCEPT CHECK 37.2

1. Are some essential elements more important than others? Explain.
2. **WHAT IF?** If an element increases the growth rate of a plant, can it be defined as an essential element?
3. **MAKE CONNECTIONS** Based on Figure 10.17, explain why hydroponically grown plants would grow much more slowly if they were not sufficiently aerated.

For suggested answers, see Appendix A.

CONCEPT 37.3

Plant nutrition often involves relationships with other organisms

To this point, we have looked at plants as exploiters of soil resources, but plants and soil have a two-way relationship. Dead plants provide much of the energy needed by soil-dwelling bacteria and fungi. Many of these organisms also benefit from sugar-rich secretions produced by living roots. Meanwhile, plants derive benefits from their associations with soil bacteria and fungi. As shown in **Figure 37.9**, mutually beneficial relationships across kingdoms and domains are not rare in nature. However, they are of particular importance to plants. We'll explore some important *mutualisms* between plants and soil bacteria and fungi, as well as some unusual, nonmutualistic forms of plant nutrition.

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2. Highlight climate change throughout the course

- Properties of water: Polar ice melting
- Photosynthesis: C3 vs C4 vs CAM
- Viruses: Emerging diseases
- Evolution: Limits of natural selection
- Evolution: Hybrid zone effects
- Diversity: Effects on phytoplankton
- Plants: Food quality vs quantity
- Animals: Reproductive cycles

Reproductive Cycles

Most animals, whether asexual or sexual, exhibit cycles in reproductive activity, often related to changing seasons. These cycles are controlled by hormones, whose secretion is in turn regulated by environmental cues. In this way, animals expend resources to reproduce only when sufficient energy sources are available and when environmental conditions favor the survival of offspring. For example, ewes (female sheep) have a reproductive cycle lasting 15–17 days. **Ovulation**, the release of mature eggs, occurs at the midpoint of each cycle. For ewes, reproductive cycles generally occur only during fall and early winter, and the length of any pregnancy is five months. Thus, most lambs are born in the early spring, when their chances of survival are optimal.

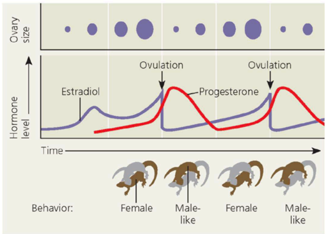
Because seasonal temperature is often an important cue for reproduction, climate change can decrease reproductive success. Researchers have discovered such an effect on caribou (wild reindeer) in Greenland. In spring, caribou migrate to calving grounds to eat sprouting plants, give birth, and care for their calves. Prior to 1993, the arrival of the caribou at the calving grounds coincided with the brief period during which the plants were nutritious and digestible. By 2006, however, average spring temperatures in the calving grounds had increased by more than 4°C, and the plants sprouted two weeks earlier. Because caribou migration is triggered by day length, not temperature, a mismatch arose between the timing of new plant growth and caribou birthing. Without adequate nutrition for the nursing females, production of caribou offspring has declined by more than 75% since 1993. To learn more about the effects of climate change on caribou and other organisms, see Make Connections Figure 56.31.

Reproductive cycles are also found among animals that can reproduce both sexually and asexually. Consider, for instance, the water flea (genus *Daphnia*). A female *Daphnia* can produce eggs of two types. One type of egg requires fertilization to develop, but the other type does not and develops instead by parthenogenesis. *Daphnia* reproduce asexually when environmental conditions are favorable and sexually during times of environmental stress. As a result, the switch between sexual and asexual reproduction is roughly linked to season.

For some asexual animal species, a cycle of reproductive behavior appears to reflect a sexual evolutionary past. In the parthenogenetic lizard species *Aspidoscelis uniparens*, reproduction is asexual, and all individuals are female. Nevertheless, these lizards have courtship and mating behaviors very similar to those of sexual species of *Aspidoscelis*. One member of each mating pair undergoes **ovulation**, the production and release of mature eggs. The other female mimics a male **(Figure 45.3a)**. Over the course of the breeding season, the two lizards alternate roles two or three times. An individual adopts female behavior prior to ovulation, when the concentration of the hormone estradiol is high, and then switches to male-like behavior after ovulation, when the concentration of the hormone progesterone is high **(Figure 45.3b)**. A female is more likely to ovulate if she is mounted at a critical time of

▼ Figure 45.3 Sexual behavior in parthenogenetic lizards. The desert grassland whiptail lizard (*Aspidoscelis uniparens*) is an all-female species. These reptiles reproduce by parthenogenesis, the development of an unfertilized egg, but ovulation is stimulated by mating behavior.

(a) Both lizards in this photograph are *A. uniparens* females. The one on top is playing the role of a male. Individuals switch sex roles two or three times during the breeding season.



(b) The changes in sexual behavior of *A. uniparens* individuals are correlated with the cycles of ovulation and changing levels of the sex hormones estradiol and progesterone. These drawings track the changes in ovary size, hormone levels, and sexual behavior of one female lizard (shown in brown).

INTERPRET THE DATA *If you plotted hormone levels for the lizard shown in gray, how would your graph differ from the graph in part (b)?*

the hormone cycle; isolated lizards lay fewer eggs than those that go through the motions of sex. These findings support the hypothesis that these parthenogenetic lizards evolved from species having two sexes and still require certain sexual stimuli for maximum reproductive success.

Sexual Reproduction: An Evolutionary Enigma

EVOLUTION Although our species and many others reproduce sexually, the existence of sexual reproduction is actually puzzling. To see why, imagine an animal population in which half the females reproduce sexually and half reproduce asexually. We'll assume that the number of offspring per female is a constant, two in this case. The two offspring of an

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2. Highlight climate change throughout the course

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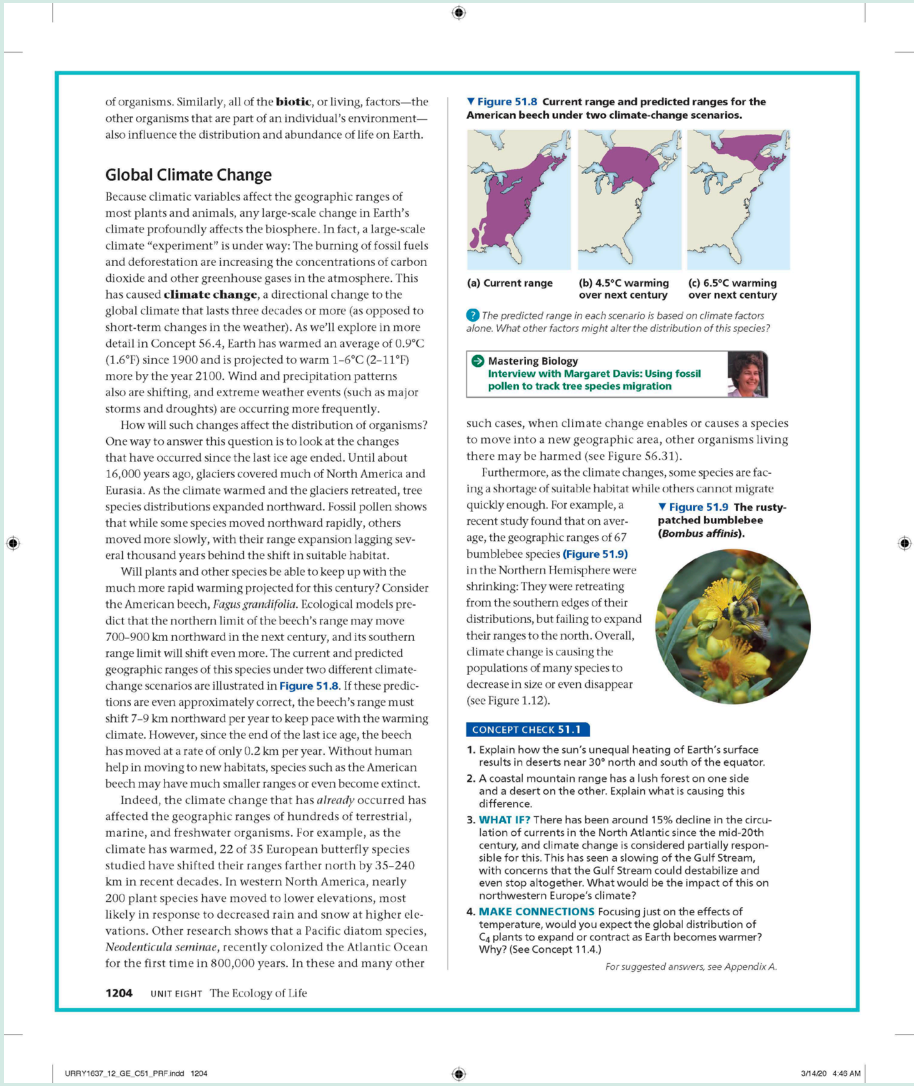
- Evolution: Limits of natural selection
- Evolution: Hybrid zone effects
- Diversity: Effects on phytoplankton
- Plants: Food quality vs quantity
- Animals: Reproductive cycles
- Ecology: Effect on biomes



of organisms. Similarly, all of the **biotic**, or living, factors—the other organisms that are part of an individual's environment—also influence the distribution and abundance of life on Earth.

Global Climate Change

Because climatic variables affect the geographic ranges of most plants and animals, any large-scale change in Earth's climate profoundly affects the biosphere. In fact, a large-scale climate "experiment" is under way: The burning of fossil fuels and deforestation are increasing the concentrations of carbon dioxide and other greenhouse gases in the atmosphere. This has caused **climate change**, a directional change to the global climate that lasts three decades or more (as opposed to short-term changes in the weather). As we'll explore in more detail in Concept 56.4, Earth has warmed an average of 0.9°C (1.6°F) since 1900 and is projected to warm 1–6°C (2–11°F) more by the year 2100. Wind and precipitation patterns also are shifting, and extreme weather events (such as major storms and droughts) are occurring more frequently.

How will such changes affect the distribution of organisms? One way to answer this question is to look at the changes that have occurred since the last ice age ended. Until about 16,000 years ago, glaciers covered much of North America and Eurasia. As the climate warmed and the glaciers retreated, tree species distributions expanded northward. Fossil pollen shows that while some species moved northward rapidly, others moved more slowly, with their range expansion lagging several thousand years behind the shift in suitable habitat.

Will plants and other species be able to keep up with the much more rapid warming projected for this century? Consider the American beech, *Fagus grandifolia*. Ecological models predict that the northern limit of the beech's range may move 700–900 km northward in the next century, and its southern range limit will shift even more. The current and predicted geographic ranges of this species under two different climate-change scenarios are illustrated in **Figure 51.8**. If these predictions are even approximately correct, the beech's range must shift 7–9 km northward per year to keep pace with the warming climate. However, since the end of the last ice age, the beech has moved at a rate of only 0.2 km per year. Without human help in moving to new habitats, species such as the American beech may have much smaller ranges or even become extinct.

Indeed, the climate change that has *already* occurred has affected the geographic ranges of hundreds of terrestrial, marine, and freshwater organisms. For example, as the climate has warmed, 22 of 35 European butterfly species studied have shifted their ranges farther north by 35–240 km in recent decades. In western North America, nearly 200 plant species have moved to lower elevations, most likely in response to decreased rain and snow at higher elevations. Other research shows that a Pacific diatom species, *Neodenticula seminae*, recently colonized the Atlantic Ocean for the first time in 800,000 years. In these and many other such cases, when climate change enables or causes a species to move into a new geographic area, other organisms living there may be harmed (see Figure 56.31).

Furthermore, as the climate changes, some species are facing a shortage of suitable habitat while others cannot migrate quickly enough. For example, a recent study found that on average, the geographic ranges of 67 bumblebee species **(Figure 51.9)** in the Northern Hemisphere were shrinking: They were retreating from the southern edges of their distributions, but failing to expand their ranges to the north. Overall, climate change is causing the populations of many species to decrease in size or even disappear (see Figure 1.12).

▼ Figure 51.8 Current range and predicted ranges for the American beech under two climate-change scenarios.

(a) Current range **(b) 4.5°C warming over next century** **(c) 6.5°C warming over next century**

? The predicted range in each scenario is based on climate factors alone. What other factors might alter the distribution of this species?

Mastering Biology
Interview with Margaret Davis: Using fossil pollen to track tree species migration

▼ Figure 51.9 The rusty-patched bumblebee (*Bombus affinis*).

CONCEPT CHECK 51.1

1. Explain how the sun's unequal heating of Earth's surface results in deserts near 30° north and south of the equator.
2. A coastal mountain range has a lush forest on one side and a desert on the other. Explain what is causing this difference.
3. **WHAT IF?** There has been around 15% decline in the circulation of currents in the North Atlantic since the mid-20th century, and climate change is considered partially responsible for this. This has seen a slowing of the Gulf Stream, with concerns that the Gulf Stream could destabilize and even stop altogether. What would be the impact of this on northwestern Europe's climate?
4. **MAKE CONNECTIONS** Focusing just on the effects of temperature, would you expect the global distribution of C_4 plants to expand or contract as Earth becomes warmer? Why? (See Concept 11.4.)

For suggested answers, see Appendix A.

1204 UNIT EIGHT The Ecology of Life

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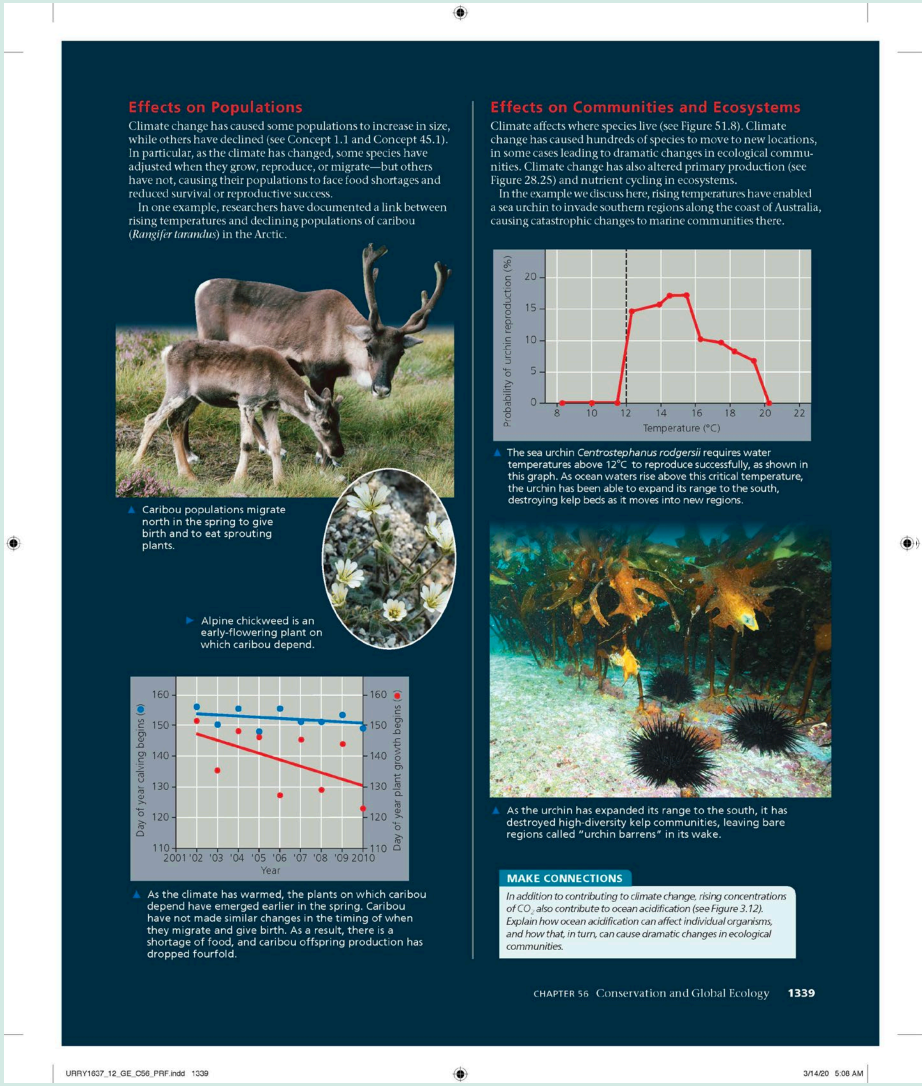
Pearson

2. Highlight climate change throughout the course

- Properties of water: Polar ice melting
- Photosynthesis: C3 vs C4 vs CAM
- Viruses: Emerging diseases
- Evolution: Limits of natural selection
- Evolution: Hybrid zone effects
- Diversity: Effects on phytoplankton
- Plants: Food quality vs quantity
- Animals: Reproductive cycles
- Ecology: Effect on biomes
- Make connections: Tying it all together



Effects on Populations

Climate change has caused some populations to increase in size, while others have declined (see Concept 1.1 and Concept 45.1). In particular, as the climate has changed, some species have adjusted when they grow, reproduce, or migrate—but others have not, causing their populations to face food shortages and reduced survival or reproductive success.

In one example, researchers have documented a link between rising temperatures and declining populations of caribou (*Rangifer tarandus*) in the Arctic.

▲ Caribou populations migrate north in the spring to give birth and to eat sprouting plants.

► Alpine chickweed is an early-flowering plant on which caribou depend.

▲ As the climate has warmed, the plants on which caribou depend have emerged earlier in the spring. Caribou have not made similar changes in the timing of when they migrate and give birth. As a result, there is a shortage of food, and caribou offspring production has dropped fourfold.

Effects on Communities and Ecosystems

Climate affects where species live (see Figure 51.8). Climate change has caused hundreds of species to move to new locations, in some cases leading to dramatic changes in ecological communities. Climate change has also altered primary production (see Figure 28.25) and nutrient cycling in ecosystems.

In the example we discuss here, rising temperatures have enabled a sea urchin to invade southern regions along the coast of Australia, causing catastrophic changes to marine communities there.

▲ The sea urchin *Centrostephanus rodgersii* requires water temperatures above 12°C to reproduce successfully, as shown in this graph. As ocean waters rise above this critical temperature, the urchin has been able to expand its range to the south, destroying kelp beds as it moves into new regions.

▲ As the urchin has expanded its range to the south, it has destroyed high-diversity kelp communities, leaving bare regions called "urchin barrens" in its wake.

MAKE CONNECTIONS

In addition to contributing to climate change, rising concentrations of CO_2 also contribute to ocean acidification (see Figure 3.12). Explain how ocean acidification can affect individual organisms, and how that, in turn, can cause dramatic changes in ecological communities.

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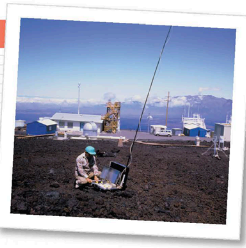
3. Have students work with data so they can

- ❖ draw their own conclusions

Scientific Skills Exercise

Graphing Data and Evaluating Evidence

How Has the Rise in Atmospheric CO_2 Concentration Changed over Time? The blue curve in Figure 56.29 shows how the concentration of CO_2 in Earth's atmosphere has changed over a span of more than 50 years. For each year in that span, scientists collected daily CO_2 concentration data and used those data to calculate the average CO_2 level for that year. In this exercise, you'll graph average CO_2 concentrations for three ten-year periods and analyze how those concentrations have changed over time.



▶ A researcher sampling the air at the Mauna Loa monitoring station, Hawaii.

Data from the Study The data in the table below are average CO_2 concentrations (in parts per million, or ppm) at the Mauna Loa monitoring station for each of the indicated years.

1969	324.6	1989	353.1	2009	387.4
1970	325.7	1990	354.4	2010	389.9
1971	326.3	1991	355.6	2011	391.7
1972	327.5	1992	356.5	2012	393.9
1973	329.7	1993	357.1	2013	396.5
1974	330.2	1994	358.8	2014	398.7
1975	331.1	1995	360.8	2015	400.8
1976	332.0	1996	362.6	2016	404.2
1977	333.8	1997	363.7	2017	406.6
1978	335.4	1998	366.7	2018	408.5

Data from National Oceanic & Atmospheric Administration, Earth System Research Laboratory, Global Monitoring Division.

INTERPRET THE DATA

1. Plot the data for each ten-year period on one graph, where the *x*-axis runs from year 1 to year 10 (producing three curves); this approach can help you to compare and contrast how the CO_2 level has changed during the three decades. Select a type of graph that is appropriate for these data, and choose a vertical axis scale that allows you to clearly see how the CO_2 concentration has changed, both from year to year and from one ten-year period to the next. (For additional information about graphs, see the Scientific Skills Review in Appendix D.)
2. For each ten-year period, what is the pattern of change in CO_2 concentration? Do the curves you have drawn suggest that the pattern has changed from decade to decade?
3. Calculate the annual rate at which the CO_2 concentration increased during each ten-year period. Perform these calculations as shown here for data from 1959 to 1968 (not in the table): in 1959 the CO_2 concentration was 316 ppm, while in 1968 it was 323. Thus, from 1959 to 1968, the CO_2 concentration increased at an average annual rate of

$$\frac{323 - 316}{9}$$

or 0.8 ppm per year (we divide by 9 because during a 10-year period of time, there are 9 year-to-year changes in CO_2 concentration).
4. (a) If the annual increase in CO_2 concentration were to remain at the level observed for 2009–2018, predict the CO_2 concentration in 2100. (b) Use your results to evaluate the effectiveness of efforts to reduce CO_2 emissions.

➔ **Instructors:** A version of this Scientific Skills Exercise can be assigned in **Mastering Biology**.

Greenhouse Gases and Climate Change

Human activities release a variety of gaseous waste products. People once thought that the vast atmosphere could absorb these materials indefinitely, but we now know that our actions can lead to **climate change**, a directional change to the global climate that lasts for three decades or more (as opposed to short-term changes in the weather).

Rising Atmospheric CO_2 Levels

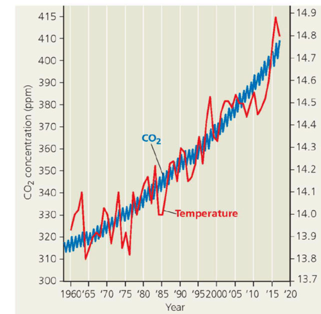
To see how human actions can cause climate change, consider atmospheric CO_2 levels. Over the past 170 years, the concentration of CO_2 in the atmosphere has been increasing as a result of the burning of fossil fuels and deforestation. Scientists estimate that the average CO_2 concentration in the atmosphere before 1850 was about 274 ppm. In 1958, a monitoring station began taking accurate measurements on Hawaii's Mauna Loa peak, a location far from cities and high enough for the atmosphere to be well mixed. At that time, the average CO_2 concentration was 315 ppm (**Figure 56.29**). By 2018, the CO_2 level exceeded 410 ppm, an increase of more than 50% since the mid-19th century. In the **Scientific Skills Exercise**, you can graph and interpret changes in CO_2 concentration that occur over three ten-year periods of time.

The increase in the concentration of atmospheric CO_2 over the last 170 years concerns scientists because of its link to increased global temperature. Much of the solar radiation that strikes the planet is emitted toward space as infrared radiation (known informally as "heat radiation"). Although CO_2, methane, water vapor, and other greenhouse gases in the atmosphere are transparent to visible light, they intercept and absorb much of the infrared radiation that Earth emits, radiating most of it back toward Earth. This process, called the **greenhouse effect**, retains some of the solar heat (**Figure 56.30**). If it were not for this greenhouse effect, the average air temperature at Earth's surface would be a frigid −18°C (−0.4°F), and most life as we know it could not exist.

As the concentrations of CO_2 and other greenhouse gases rise, more solar heat is retained, thereby increasing the temperature of our planet. So far, Earth has warmed by an average of 0.9°C (1.6°F) since 1900. Much of this warming has occurred recently: 18 of the 19 warmest years on record have occurred since 2001, with 2016 being the warmest year ever (see Figure 56.29).

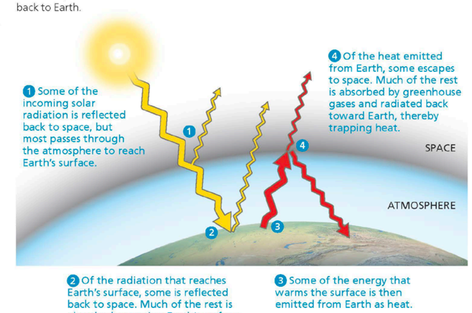
As our planet warms, the climate is changing in other ways as well: Wind and precipitation patterns are shifting,

▼ **Figure 56.29 Increase in atmospheric carbon dioxide concentration at Mauna Loa, Hawaii, and average global temperatures.** Aside from normal seasonal fluctuations, the CO_2 concentration (blue curve) increased steadily since 1958. Though average global temperatures (red curve) fluctuated a great deal over time, there is a clear warming trend.



➔ Mastering Biology **MP3 Tutor: Global Warming**

▼ **Figure 56.30 The greenhouse effect.** Carbon dioxide and other greenhouse gases in the atmosphere absorb heat emitted from Earth's surface and then radiate much of that heat back to Earth.



➔ Mastering Biology **HHMI Animation: Greenhouse Effect**
Animation: The Global Carbon Cycle and the Greenhouse Effect

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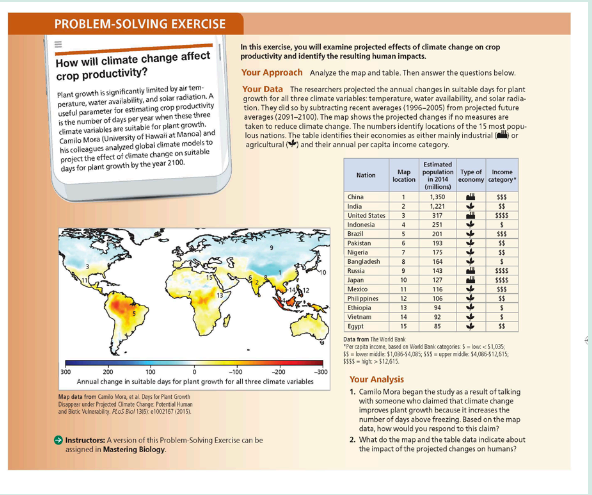
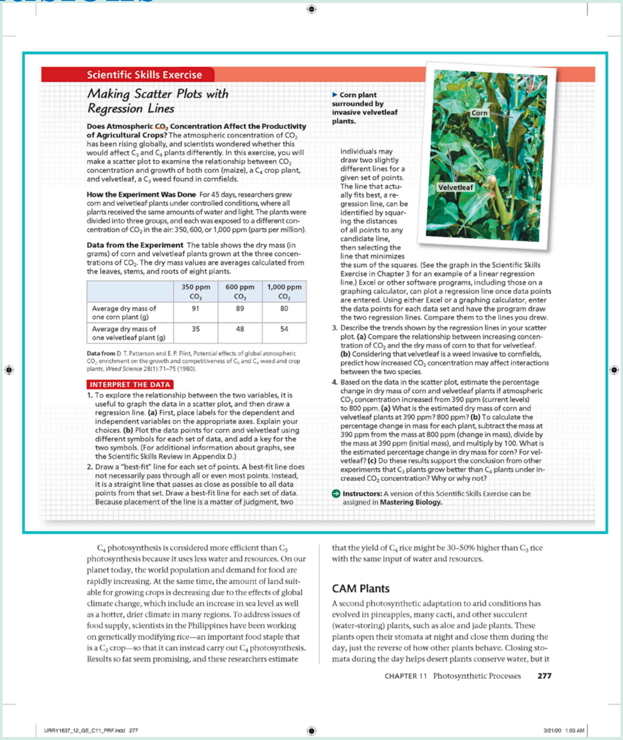
3. Have students work with data so they can

- draw their own conclusions



PROBLEM-SOLVING EXERCISE

How will climate change affect crop productivity?



Scientific Skills Exercise

Making Scatter Plots with Regression Lines

PROBLEM-SOLVING EXERCISE

Can an insect outbreak threaten a forest's ability to absorb CO_2 from the atmosphere?

Pearson

3. Have students work with data so they can

- draw their own conclusions
- learn how climate models are constructed and tested

decreased winter snowfall, and a lengthening of the summer dry period. Since the latter half of the 20th century, otherwise healthy forests have experienced a steady increase in the percentage of trees that die each year. Higher temperatures and more frequent droughts also increase the likelihood of fires (see Figure 55.8). In boreal forests of western North America and Russia, for example, fires have burned twice the usual area in recent decades, again leading to widespread tree mortality. As the climate continues to warm, other changes in the geographic distribution of precipitation are likely, such as agricultural areas of the central United States becoming much drier.

Climate change has already affected many other ecosystems as well. In Europe and Asia, for example, plants are producing leaves earlier in the spring, while in tropical regions, the growth and survival of some species of coral have declined as water temperatures have risen. Recently, Australia's Great Barrier Reef had a catastrophic decline: The combined effects of two consecutive marine heat waves (one in 2016, another in 2017) killed so many corals that two-thirds of the reef was severely degraded—so degraded that some scientists worry it may never recover. A key take-home message from these examples is that a given effect of climate change may, in turn, cause a series of other biological changes. The exact nature of such cascading biological effects can be hard to predict, but it is clear that the more our planet warms, the more severely its ecosystems will be affected.

Modeling Climate Change

At the current rates that human activities are adding CO_2 and other greenhouse gases to the atmosphere, global models predict that Earth's temperature will rise by an additional 3°C (5°F) by the end of the 21st century. What data are used to construct such models, and are their predictions accurate?

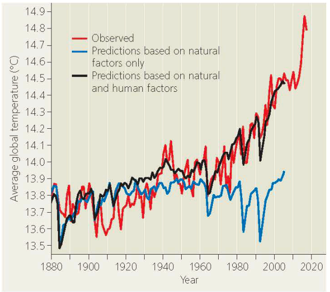
Global models are constructed using data on factors that affect the absorption of solar radiation at Earth's surface. These data are crucial because global temperatures rise when more solar radiation is absorbed by Earth's surface, and they fall when less solar radiation is absorbed by the surface. Natural factors that affect the absorption of solar radiation include an 11-year solar cycle and volcanic explosions. During each round of the solar cycle, the amount of energy emitted by the sun increases and decreases in a regular way, thereby contributing to a well-understood rise or fall in global temperatures at different points in time. Volcanic explosions emit gases and tiny particles that block incoming solar radiation, thereby contributing to a temporary drop in global temperatures. (Changes in the shape of Earth's orbit around the sun also contribute to increases or decreases in global temperatures, but those changes occur gradually over tens of thousands of years and hence are not a cause of recent climate change.)

Scientists also have collected vast amounts of data on how human activities affect absorption of solar radiation. When we burn fossil fuels for electricity, heat, and transportation, we cause CO_2 and other greenhouse gases to be released to the atmosphere. As shown in Figure 56.30, adding CO_2 and other greenhouse gases to the atmosphere increases the absorption of solar radiation, leading to global warming. Other human activities decrease the absorption of solar radiation, thereby tending to reduce global temperatures. For example, dust released by plowing fields and the emission of gases such as sulfur dioxide (SO_2) both decrease the absorption of solar energy, thus reducing global temperatures.

Each of these and other types of data provides a single, well-understood piece of a grand puzzle—how Earth's temperature is affected by a combination of natural and human factors. Scientists use computer models to put the pieces of this puzzle together. Each year, large amounts of data on natural and human factors that affect the absorption of solar radiation are entered into the model, which then sums their effects to predict Earth's temperature. Over time, predictions from these models have become increasingly accurate: Global climate models can now reproduce observed changes such as the increase in global warming that has occurred since the 1950s **(Figure 56.32)** and the global cooling that results from volcanic eruptions.

But why go to all this trouble developing models when Earth's temperature can be measured each year? The reason is that we have only one Earth and hence cannot perform

▼ Figure 56.32 Factors contributing to rising global temperatures. Scientists have measured the temperature of our planet since 1880. These observed temperatures (red) can be compared to results from climate models that incorporate only natural factors that affect global temperatures (blue) and from models that incorporate both natural and human factors (black).



VISUAL SKILLS *Describe how well the results shown in the blue and black curves match observed temperature changes over time. Use those results to evaluate whether human activities such as burning fossil fuels have contributed to observed temperature changes over time.*

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4. Emphasize importance of students' role in continuing the public conversation about possible solutions

experiments to determine how emitting different amounts of CO_2 affects the temperature of our planet. Instead, because we know that global climate models yield accurate predictions, we can use the models to perform "if-then" thought experiments: *If* we add a certain amount of CO_2 to the atmosphere, *then* global temperatures will rise by a certain number of degrees.

The predictions are sobering. If we continue with "business as usual," where emissions of CO_2 continue at current levels, by 2100 Earth's temperature will likely be 4°C higher than it was in 1900—an increase that would have dire effects for all of Earth's species, including our own. Moreover, even if all CO_2 emissions were to stop immediately, the temperature of our planet would continue to rise by an additional 0.6°C, making it 1.5°C higher in 2100 than it was in 1900. Earth will continue to warm long after emissions stop because it takes decades for the CO_2 already emitted to warm the oceans, and thus that long for the full effect of past emissions to be realized.

Finding Solutions to Address Climate Change

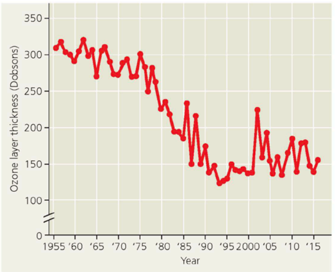
We will need many approaches to slow global warming and other aspects of climate change. Quick progress can be made by using energy more efficiently and by replacing fossil fuels with renewable solar and wind power and, more controversially, with nuclear power. Today, coal, gasoline, wood, and other organic fuels remain central to industrialized societies and cannot be burned without releasing CO_2. Stabilizing CO_2 emissions will require concerted international effort and changes in both personal lifestyles and industrial processes.

Progress toward finding solutions to address climate change was made in 2015 when all nations agreed—for the first time—to take steps to reduce CO_2 emissions and limit the extent to which global temperatures ultimately rise. This international effort, known as the Paris Agreement, has been ratified by 169 nations, including China, the United States, and all other nations that emit substantial quantities of CO_2 and other greenhouse gases. The effectiveness of the agreement was recently called into question, however, when the United States announced its intention to withdraw from the agreement by 2020. This setback highlights a potential difference between what we know and what we choose to do. An overwhelming amount of evidence indicates that climate change is real, that the rise in global temperatures since the 1950s was caused primarily by human actions, and that there will be negative consequences for human societies and all life on Earth unless we act now. What we choose to do with this information is up to us.

Depletion of Atmospheric Ozone

Like carbon dioxide and other greenhouse gases, atmospheric ozone (O_3) has also changed in concentration because of human activities. Life on Earth is protected from the damaging effects of ultraviolet (UV) radiation by a layer of ozone located in the stratosphere 17–25 km above Earth's surface. However, satellite studies of the atmosphere show that the springtime ozone

▼ Figure 56.33 Thickness of the October ozone layer over Antarctica, in units called Dobsons.

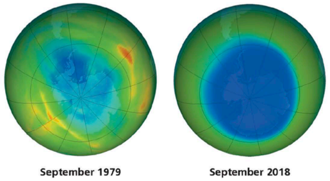


layer over Antarctica has thinned substantially since the mid-1970s **(Figure 56.33)**. The destruction of atmospheric ozone results primarily from the accumulation of chlorofluorocarbons (CFCs), chemicals once widely used in refrigeration and manufacturing. In the stratosphere, chlorine atoms released from CFCs react with ozone, reducing it to molecular O_2. Subsequent chemical reactions liberate the chlorine, allowing it to react with other ozone molecules in a catalytic chain reaction.

The thinning of the ozone layer is most apparent over Antarctica in spring, where cold, stable air allows the chain reaction to continue **(Figure 56.34)**. The magnitude of ozone depletion and the size of the ozone hole have been slightly smaller in recent years than the average for the last 20 years, but the hole still sometimes extends as far as the southernmost portions of Australia, New Zealand, and South America. At the more heavily populated middle latitudes, ozone levels have decreased 2–10% during the past 20 years.

Decreased ozone levels in the stratosphere increase the intensity of UV rays reaching Earth's surface. The consequences

▼ Figure 56.34 Erosion of Earth's ozone shield. The ozone hole over Antarctica is visible as the dark blue patch in these images based on atmospheric data.



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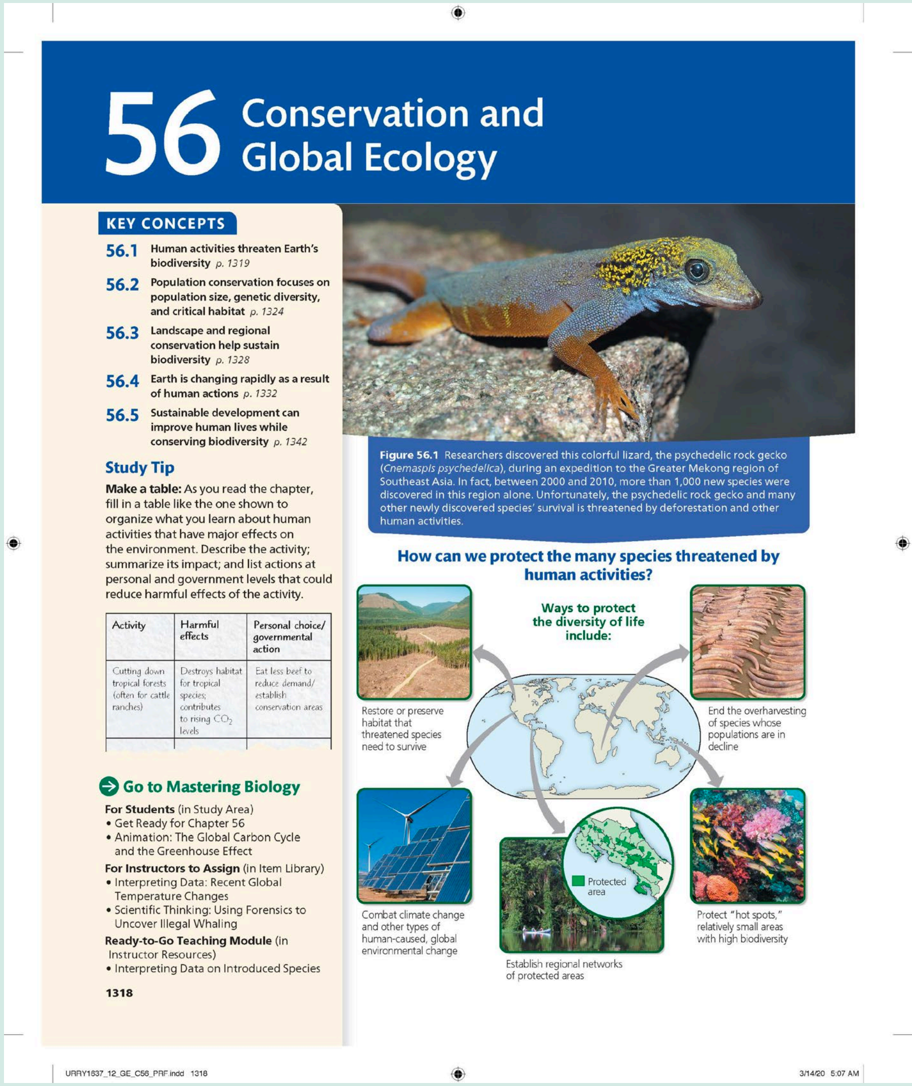
4. Emphasize importance of students' role in continuing the public conversation about possible solutions



56 Conservation and Global Ecology

KEY CONCEPTS

Study Tip

Make a table: As you read the chapter, fill in a table like the one shown to organize what you learn about human activities that have major effects on the environment. Describe the activity; summarize its impact; and list actions at personal and government levels that could reduce harmful effects of the activity.

Activity	Harmful effects	Personal choice/ governmental action
Cutting down tropical forests (often for cattle ranches)	Destroys habitat for tropical species; contributes to rising CO_2 levels	Eat less beef to reduce demand/ establish conservation areas

Go to Mastering Biology

For Students (in Study Area)
- Get Ready for Chapter 56
- Animation: The Global Carbon Cycle and the Greenhouse Effect

For Instructors to Assign (in Item Library)
- Interpreting Data: Recent Global Temperature Changes
- Scientific Thinking: Using Forensics to Uncover Illegal Whaling

Ready-to-Go Teaching Module (in Instructor Resources)
- Interpreting Data on Introduced Species

Figure 56.1 Researchers discovered this colorful lizard, the psychedelic rock gecko (*Cnemaspis psychedelica*), during an expedition to the Greater Mekong region of Southeast Asia. In fact, between 2000 and 2010, more than 1,000 new species were discovered in this region alone. Unfortunately, the psychedelic rock gecko and many other newly discovered species' survival is threatened by deforestation and other human activities.

How can we protect the many species threatened by human activities?

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Summary

1. Start from the beginning of the course
2. Highlight CC frequently throughout the course, at different levels of biology (examples)
3. Have students work with data so they can draw their own conclusions, and see how models are built
4. Emphasize importance of students' role in continuing the public conversation about possible solutions

Digital Learning NOW

Thank you for joining us!

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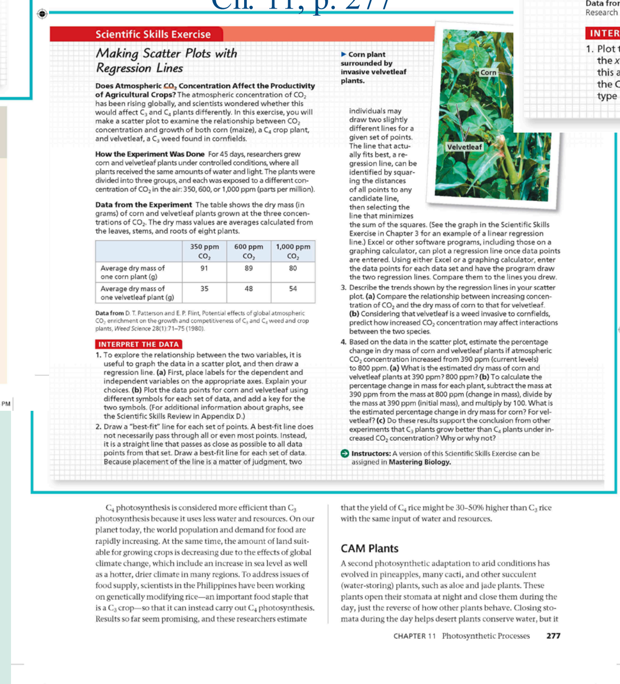
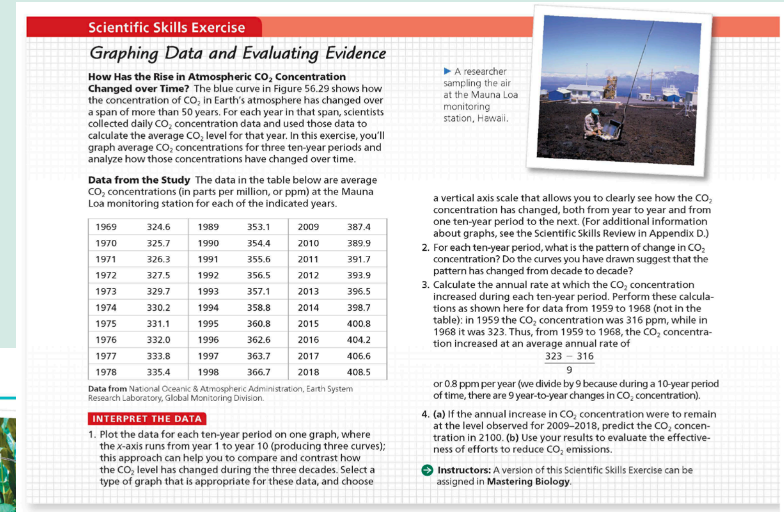
Pearson

In Class Activities

Ch. 2, p. 102

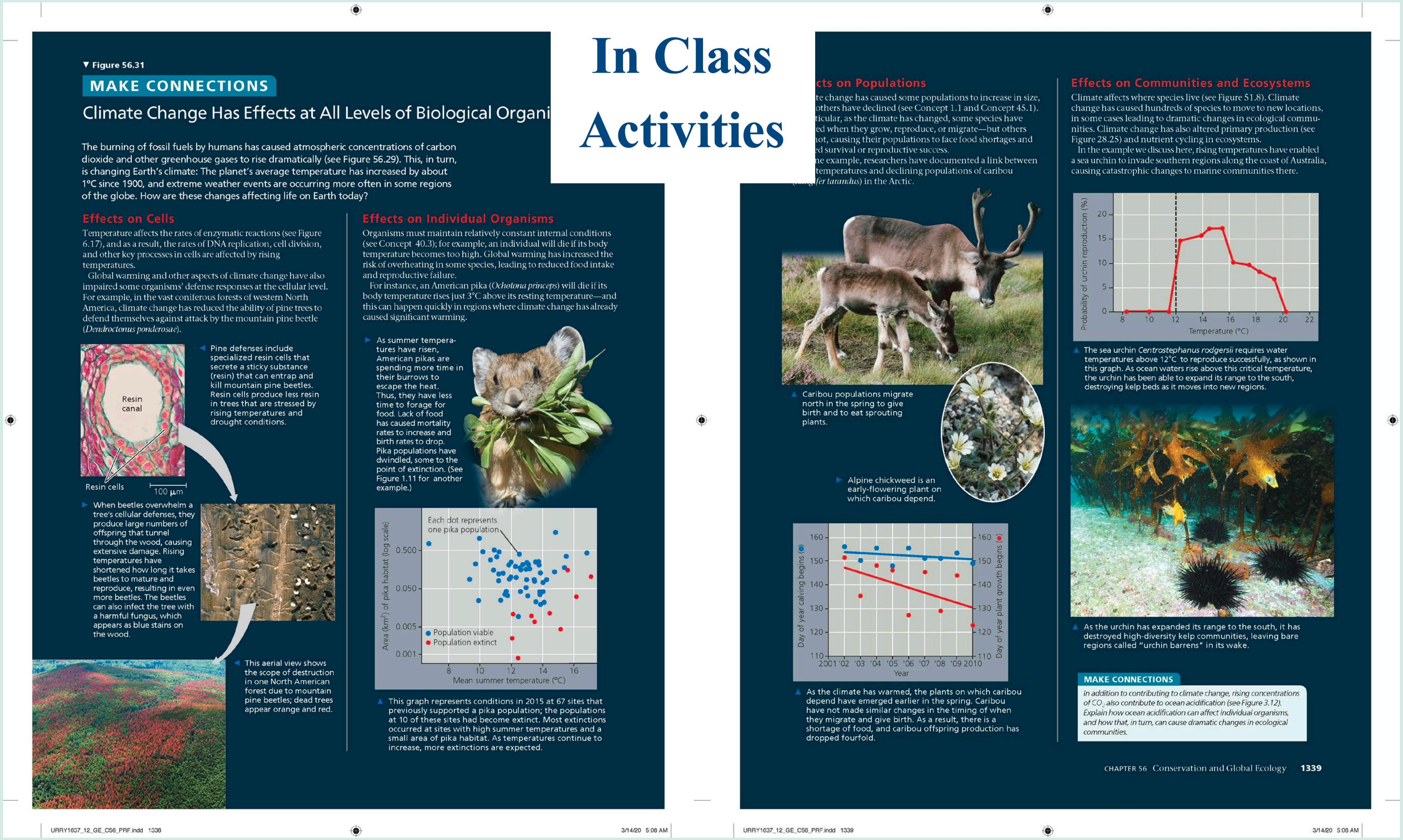


Ch. 11, p. 277



Ch. 56, p. 1337

In Class Activities



▼ Figure 56.31

MAKE CONNECTIONS

Climate Change Has Effects at All Levels of Biological Organi

The burning of fossil fuels by humans has caused atmospheric concentrations of carbon dioxide and other greenhouse gases to rise dramatically (see Figure 56.29). This, in turn, is changing Earth's climate: The planet's average temperature has increased by about 1°C since 1900, and extreme weather events are occurring more often in some regions of the globe. How are these changes affecting life on Earth today?

Effects on Cells

Temperature affects the rates of enzymatic reactions (see Figure 6.17), and as a result, the rates of DNA replication, cell division, and other key processes in cells are affected by rising temperatures.

Global warming and other aspects of climate change have also impaired some organisms' defense responses at the cellular level. For example, in the vast coniferous forests of western North America, climate change has reduced the ability of pine trees to defend themselves against attack by the mountain pine beetle (*Dendroctonus ponderosae*).

◀ Pine defenses include specialized resin cells that secrete a sticky substance (resin) that can entrap and kill mountain pine beetles. Resin cells produce less resin in trees that are stressed by rising temperatures and drought conditions.

▶ When beetles overwhelm a tree's cellular defenses, they produce large numbers of offspring that tunnel through the wood, causing extensive damage. Rising temperatures have shortened how long it takes beetles to mature and reproduce, resulting in even more beetles. The beetles can also infect the tree with a harmful fungus, which appears as blue stains on the wood.

◀ This aerial view shows the scope of destruction in one North American forest due to mountain pine beetles; dead trees appear orange and red.

Effects on Individual Organisms

Organisms must maintain relatively constant internal conditions (see Concept 40.3); for example, an individual will die if its body temperature becomes too high. Global warming has increased the risk of overheating in some species, leading to reduced food intake and reproductive failure.

For instance, an American pika (*Ochotona princeps*) will die if its body temperature rises just 3°C above its resting temperature—and this can happen quickly in regions where climate change has already caused significant warming.

▶ As summer temperatures have risen, American pikas are spending more time in their burrows to escape the heat. Thus, they have less time to forage for food. Lack of food has caused mortality rates to increase and birth rates to drop. Pika populations have dwindled, some to the point of extinction. (See Figure 1.11 for another example.)

▲ This graph represents conditions in 2015 at 67 sites that previously supported a pika population; the populations at 10 of these sites had become extinct. Most extinctions occurred at sites with high summer temperatures and a small area of pika habitat. As temperatures continue to increase, more extinctions are expected.

…cts on Populations

…te change has caused some populations to increase in size, …others have declined (see Concept 1.1 and Concept 45.1). …ticular, as the climate has changed, some species have …ed when they grow, reproduce, or migrate—but others …not, causing their populations to face food shortages and …ed survival or reproductive success.

…ne example, researchers have documented a link between …temperatures and declining populations of caribou (…*fer tarandus*) in the Arctic.

▲ Caribou populations migrate north in the spring to give birth and to eat sprouting plants.

▶ Alpine chickweed is an early-flowering plant on which caribou depend.

▲ As the climate has warmed, the plants on which caribou depend have emerged earlier in the spring. Caribou have not made similar changes in the timing of when they migrate and give birth. As a result, there is a shortage of food, and caribou offspring production has dropped fourfold.

Effects on Communities and Ecosystems

Climate affects where species live (see Figure 51.8). Climate change has caused hundreds of species to move to new locations, in some cases leading to dramatic changes in ecological communities. Climate change has also altered primary production (see Figure 28.25) and nutrient cycling in ecosystems.

In the example we discuss here, rising temperatures have enabled a sea urchin to invade southern regions along the coast of Australia, causing catastrophic changes to marine communities there.

▲ The sea urchin *Centrostephanus rodgersii* requires water temperatures above 12°C to reproduce successfully, as shown in this graph. As ocean waters rise above this critical temperature, the urchin has been able to expand its range to the south, destroying kelp beds as it moves into new regions.

▲ As the urchin has expanded its range to the south, it has destroyed high-diversity kelp communities, leaving bare regions called "urchin barrens" in its wake.

MAKE CONNECTIONS

In addition to contributing to climate change, rising concentrations of CO_2 also contribute to ocean acidification (see Figure 3.12). Explain how ocean acidification can affect individual organisms, and how that, in turn, can cause dramatic changes in ecological communities.

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In Class Activities (shorter time)

decreased winter snowfall, and a lengthening of the summer dry period. Since the latter half of the 20th century, otherwise healthy forests have experienced a steady increase in the percentage of trees that die each year. Higher temperatures and more frequent droughts also increase the likelihood of fires (see Figure 55.8). In boreal forests of western North America and Russia, for example, fires have burned twice the usual area in recent decades, again leading to widespread tree mortality. As the climate continues to warm, other changes in the geographic distribution of precipitation are likely, such as agricultural areas of the central United States becoming much drier.

Climate change has already affected many other ecosystems as well. In Europe and Asia, for example, plants are producing leaves earlier in the spring, while in tropical regions, the growth and survival of some species of coral have declined as water temperatures have risen. Recently, Australia's Great Barrier Reef had a catastrophic decline: The combined effects of two consecutive marine heat waves (one in 2016, another in 2017) killed so many corals that two-thirds of the reef was severely degraded—so degraded that some scientists worry it may never recover. A key take-home message from these examples is that a given effect of climate change may, in turn, cause a series of other biological changes. The exact nature of such cascading biological effects can be hard to predict, but it is clear that the more our planet warms, the more severely its ecosystems will be affected.

Modeling Climate Change

At the current rates that human activities are adding CO_2 and other greenhouse gases to the atmosphere, global models predict that Earth's temperature will rise by an additional 3°C (5°F) by the end of the 21st century. What data are used to construct such models, and are their predictions accurate?

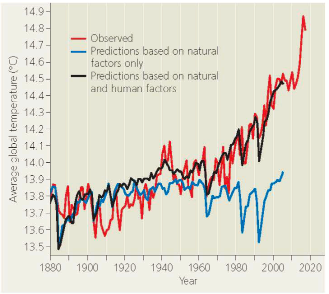
Global models are constructed using data on factors that affect the absorption of solar radiation at Earth's surface. These data are crucial because global temperatures rise when more solar radiation is absorbed by Earth's surface, and they fall when less solar radiation is absorbed by the surface. Natural factors that affect the absorption of solar radiation include an 11-year solar cycle and volcanic explosions. During each round of the solar cycle, the amount of energy emitted by the sun increases and decreases in a regular way, thereby contributing to a well-understood rise or fall in global temperatures at different points in time. Volcanic explosions emit gases and tiny particles that block incoming solar radiation, thereby contributing to a temporary drop in global temperatures. (Changes in the shape of Earth's orbit around the sun also contribute to increases or decreases in global temperatures, but those changes occur gradually over tens of thousands of years and hence are not a cause of recent climate change.)

Scientists also have collected vast amounts of data on how human activities affect absorption of solar radiation. When we burn fossil fuels for electricity, heat, and transportation, we cause CO_2 and other greenhouse gases to be released to the atmosphere. As shown in Figure 56.30, adding CO_2 and other greenhouse gases to the atmosphere increases the absorption of solar radiation, leading to global warming. Other human activities decrease the absorption of solar radiation, thereby tending to reduce global temperatures. For example, dust released by plowing fields and the emission of gases such as sulfur dioxide (SO_2) both decrease the absorption of solar energy, thus reducing global temperatures.

Each of these and other types of data provides a single, well-understood piece of a grand puzzle—how Earth's temperature is affected by a combination of natural and human factors. Scientists use computer models to put the pieces of this puzzle together. Each year, large amounts of data on natural and human factors that affect the absorption of solar radiation are entered into the model, which then sums their effects to predict Earth's temperature. Over time, predictions from these models have become increasingly accurate: Global climate models can now reproduce observed changes such as the increase in global warming that has occurred since the 1950s (**Figure 56.32**) and the global cooling that results from volcanic eruptions.

But why go to all this trouble developing models when Earth's temperature can be measured each year? The reason is that we have only one Earth and hence cannot perform

▼ **Figure 56.32 Factors contributing to rising global temperatures.** Scientists have measured the temperature of our planet since 1880. These observed temperatures (red) can be compared to results from climate models that incorporate only natural factors that affect global temperatures (blue) and from models that incorporate both natural and human factors (black).



VISUAL SKILLS *Describe how well the results shown in the blue and black curves match observed temperature changes over time. Use those results to evaluate whether human activities such as burning fossil fuels have contributed to observed temperature changes over time.*

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PSE, Ch. 39, p. 917

Outside-of-class activities

PROBLEM-SOLVING EXERCISE

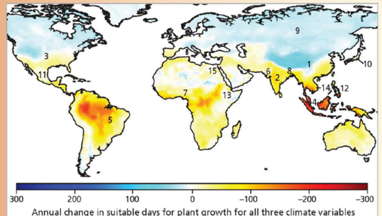
How will climate change affect crop productivity?

Plant growth is significantly limited by air temperature, water availability, and solar radiation. A useful parameter for estimating crop productivity is the number of days per year when these three climate variables are suitable for plant growth. Camilo Mora (University of Hawaii at Manoa) and his colleagues analyzed global climate models to project the effect of climate change on suitable days for plant growth by the year 2100.

In this exercise, you will examine projected effects of climate change on crop productivity and identify the resulting human impacts.

Your Approach Analyze the map and table. Then answer the questions below.

Your Data The researchers projected the annual changes in suitable days for plant growth for all three climate variables: temperature, water availability, and solar radiation. They did so by subtracting recent averages (1996–2005) from projected future averages (2091–2100). The map shows the projected changes if no measures are taken to reduce climate change. The numbers identify locations of the 15 most populous nations. The table identifies their economies as either mainly industrial (🏭) or agricultural (🌱) and their annual per capita income category.



Map data from Camilo Mora, et al. Days for Plant Growth Disappear under Projected Climate Change: Potential Human and Biotic Vulnerability. *PLoS Biol* 13(6): e1002167 (2015).

Nation	Map location	Estimated population in 2014 (millions)	Type of economy	Income category*
China	1	1,350	🏭	$$$
India	2	1,221	🌱	$$
United States	3	317	🏭	$$$$
Indonesia	4	251	🌱	$
Brazil	5	201	🌱	$$$
Pakistan	6	193	🌱	$$
Nigeria	7	175	🌱	$$
Bangladesh	8	164	🌱	$
Russia	9	143	🏭	$$$$
Japan	10	127	🏭	$$$$
Mexico	11	116	🌱	$$$
Philippines	12	106	🌱	$$
Ethiopia	13	94	🌱	$
Vietnam	14	92	🌱	$
Egypt	15	85	🌱	$$

Data from The World Bank.
*Per capita income, based on World Bank categories: $ = low: < $1,035; $$ = lower middle: $1,036–$4,085; $$$ = upper middle: $4,086–$12,615; $$$$ = high: > $12,615.

Your Analysis

1. Camilo Mora began the study as a result of talking with someone who claimed that climate change improves plant growth because it increases the number of days above freezing. Based on the map data, how would you respond to this claim?
2. What do the map and table data indicate about the impact of the projected changes on humans?

Instructors: A version of this Problem-Solving Exercise can be assigned in **Mastering Biology**.

Drought

On a sunny, dry day, a plant may wilt because its water loss by transpiration exceeds water absorption from the soil. Prolonged drought, of course, will kill a plant, but plants have control systems that enable them to cope with less extreme water deficits.

Many of a plant's responses to water deficit help the plant conserve water by reducing the rate of transpiration. Water deficit in a leaf causes stomata to close, thereby slowing transpiration dramatically (see Figure 36.14). Water deficit stimulates increased synthesis and release of abscisic acid in the leaves; this hormone helps keep stomata closed by acting on guard cell membranes. Leaves respond to water deficit in several other ways. For example, when the leaves of grasses wilt, they roll into a tubelike shape that reduces transpiration by exposing less leaf surface to dry air and wind. Other plants, such as ocotillo (see Figure 36.15), shed their leaves in response to seasonal drought. Although these leaf responses conserve water, they also reduce photosynthesis, which is one reason why a drought diminishes crop yield. Plants can even take advantage of early warnings in the form of chemical signals from wilting neighbors and prime themselves to respond more readily and intensely to impending drought stress (see the **Scientific Skills Exercise**).

pported by an overwhelming amount idence *(pp. 510–518)*

e directly observed natural selection leading to
ny studies in diverse organisms.
e characteristics because of common descent
because natural selection affects indepen-
species in similar environments in similar ways
volution).
t past organisms differed from living organisms,
es have become extinct, and that species have
g periods of time; fossils also document the
igin of new groups of organisms.
eory can explain some **biogeographic** patterns.

different lines of evidence supporting the hypothesis ended from land mammals and are closely related to s.

UNDERSTANDING

e Self-Quiz questions 1–5 can be found in the Mastering Biology.

CONNECTION Explain why anatomical and
tures often fit a similar nested pattern. In addition,
cess that can cause this not to be the case.

NQUIRY • DRAW IT Mosquitoes resistant to the
first appeared in India in 1959, but now are found
e world. (a) Graph the data in the table below.
ining the graph, hypothesize why the percentage
resistant to DDT rose rapidly. (c) Suggest an
or the global spread of DDT resistance.

Month	0	8	12
Mosquitoes Resistant* to DDT	4%	45%	77%

*Mosquitoes were considered resistant if they were not killed within 1 hour of receiving a dose of 4% DDT.

Data from C. F. Curtis et al., Selection for and against insecticide resistance and possible methods of inhibiting the evolution of resistance in mosquitoes, *Ecological Entomology* 3:273–287 (1978).

8. **WRITE ABOUT A THEME: INTERACTIONS** Write a short essay (about 100–150 words) evaluating whether changes to an organism's physical environment are likely to result in evolutionary change. Use an example to support your reasoning.

9. **SYNTHESIZE YOUR KNOWLEDGE**

This honeypot ant (genus *Myrmecocystus*) can store liquid food inside its expandable abdomen. Consider other ants you are familiar with, and explain how a honeypot ant exemplifies three key features of life: adaptation, unity, and diversity.

For selected answers, see Appendix A.

Explore Scientific Papers with Science in the Classroom AAAS
How are some coral reefs responding to climate change?
Go to "Take the Heat" at www.scienceintheclassroom.org.
Instructors: Questions can be assigned in Mastering Biology.

Science in the Classroom (AAAS) – p. 519

Chapter Openers

- **Chapter Openers** have been re-envisioned and are now organized around new elements that provide students with the tools and approaches they can use in achieving the chapter's learning objectives.

Pearson

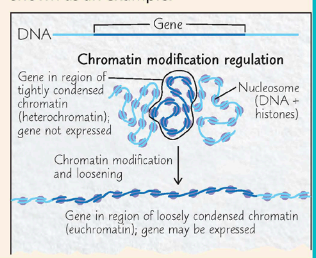
18 Control of Gene Expression

KEY CONCEPTS

Figure 18.1 *Anableps anableps*, or "cuatro ojos" ("four eyes"), glides through lakes and ponds in South America, the upper half of each eye protruding from the water. The eye's upper half is well-suited for aerial vision and the lower half for aquatic vision. All eye cells, however, contain the same genes.

Study Tip

Make a visual study guide: Draw a region of DNA representing a gene. For each level of gene regulation that you read about, draw a sketch of your gene being regulated at that level. A drawing of chromatin modification regulation is shown as an example.



Go to Mastering Biology

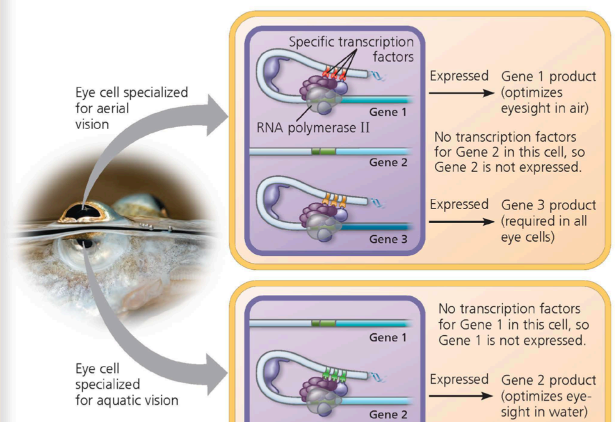
For Students (in Study Area)
- Get Ready for Chapter 18
- Animation: Control of Gene Expression
- Animation: Causes of Cancer

For Instructors to Assign (in Item Library)
- Tutorial: Regulation of Gene Expression in Eukaryotes
- Scientific Skills Exercise: Analyzing DNA Deletion Experiments

Ready-to-Go Teaching Module (in Instructor Resources)
- The *trp* and *lac* Operons (Concept 18.1)

How can two cells with the same set of genes function differently?

To be expressed, each gene requires a particular set of transcription factors. Different cells have different sets of specific transcription factors.



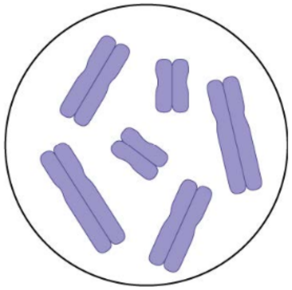
Differential gene expression is the expression of different genes by cells with the same genome. The uniquely expressed genes allow cells to carry out their specific function.

Checkpoint Interactive Questions

CheckPoint Interactive Questions confront student misconceptions with an integrated series of questions and answer-specific feedback.

CheckPoint: Counting Chromosomes

Answer a few questions to be sure you've got this before you move on.



This cell is about to undergo mitosis. How many chromosomes are shown in it?

- ○ 12
- ○ 3
- ○ 46
- ○ 6

Submit